Signal Shaping Summary and Issues

General Larsoft Meeting
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Data Flow

- SimChannel data product represents simulated charge arriving at readout wire vs. time.
- SimWire module simulates response of readout, produces RawDigit data product.
- CalWire module approximately inverts readout response. Wire data product should ideally be as close as possible to original SimChannel.

SimWire and Readout Response

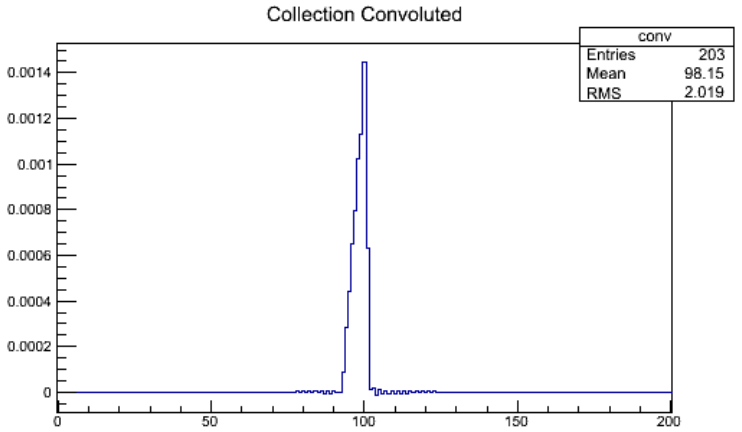
- Readout response (RawDigit) is modeled by convoluting charge (SimChannel) with a response function and adding noise.
  - (raw data) = (response function) * (charge) + (noise).
- Response has two components, which are field response (electrostatically induced charge) and electronics response.
  - (response function) = (field response) * (electronics response).
- Above relations hold in time domain (* is convolution integral) or frequency domain (* is multiplication).
  - Frequency domain representation of the response function is also called the convolution kernel.

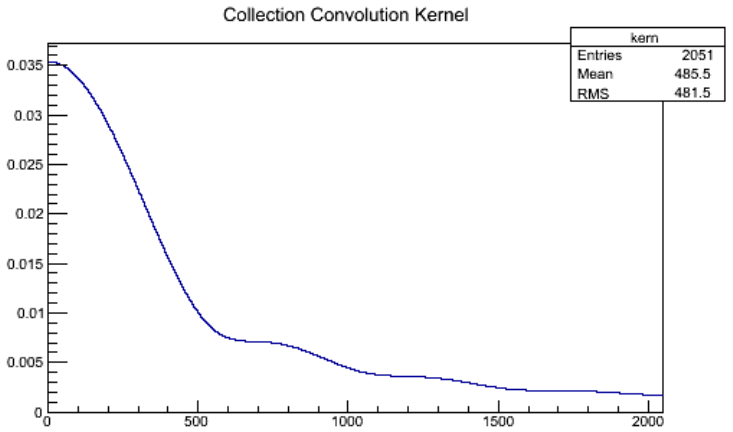
Microboone Response Functions

Response Function
(Time domain)

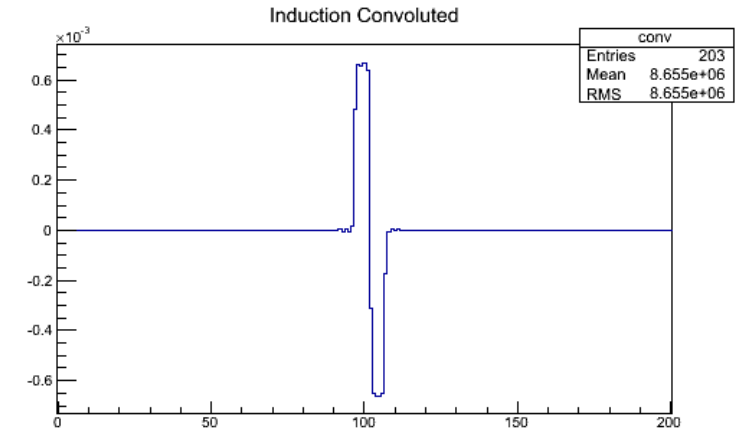
Convolution kernel
(Frequency domain)

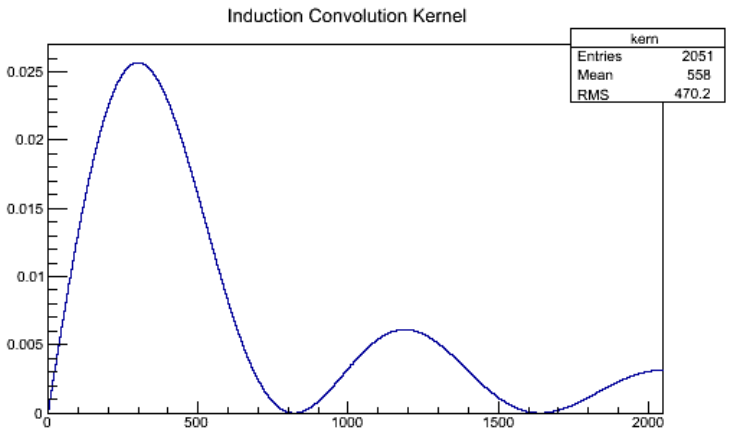
Collection





Induction





CalWire and Deconvolution

- Reconstructed charge (Wire) is modeled by convoluting raw data (RawDigit) with a so-called deconvolution kernel.
  - (reconstructed charge) = (deconvolution kernel) * (raw data).
- Deconvolution kernel is constructed from filter function and inverse of convolution kernel.
  - (deconvolution kernel) = (filter function) / (response function).
- The filter function is necessary because the response function (aka convolution kernel) can have frequencies where it is zero or so small that raw data is dominated by noise.

Combined SimWire + CalWire

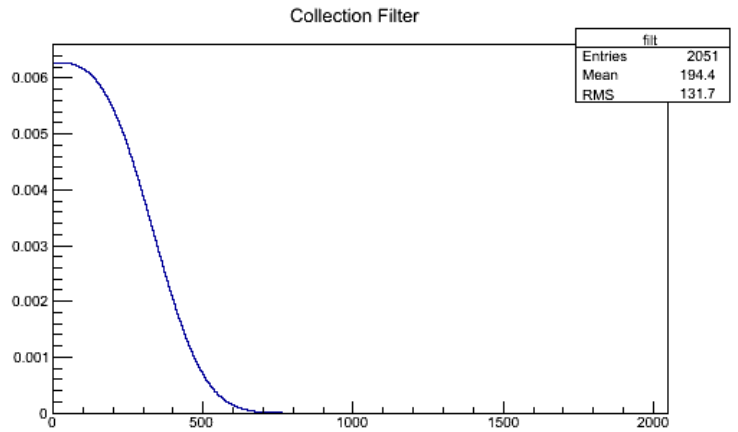
- The net effect of SimWire + CalWire is as follows.
  - (reconstructed charge) = (filter function) * (charge)
    + (deconvolution kernel) * (noise)
- A real, symmetric filter function guarantees no net time offset between reconstructed charge (Wire) and charge (SimChannel).

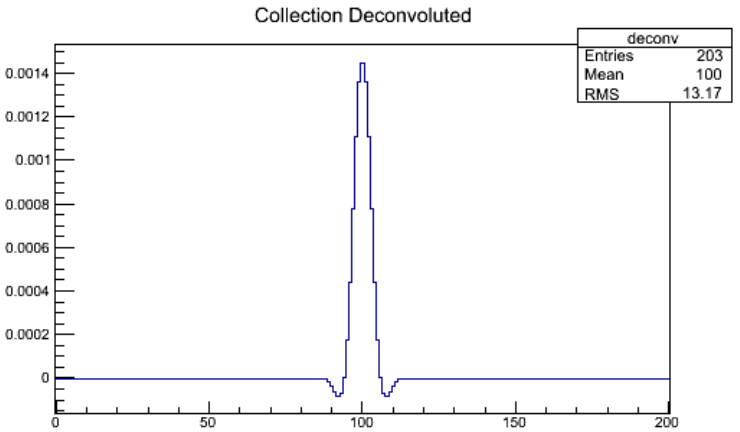
Microboone Filter Functions

Frequency domain

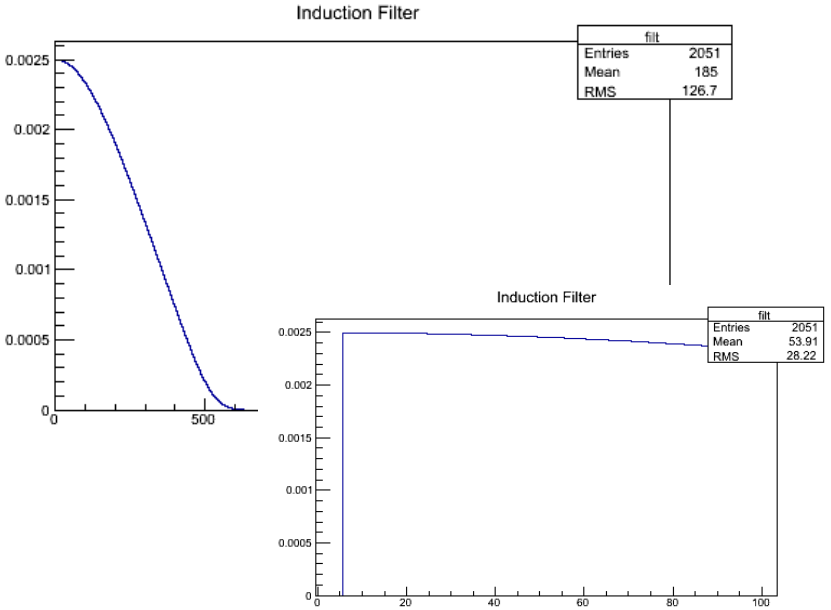
Time domain

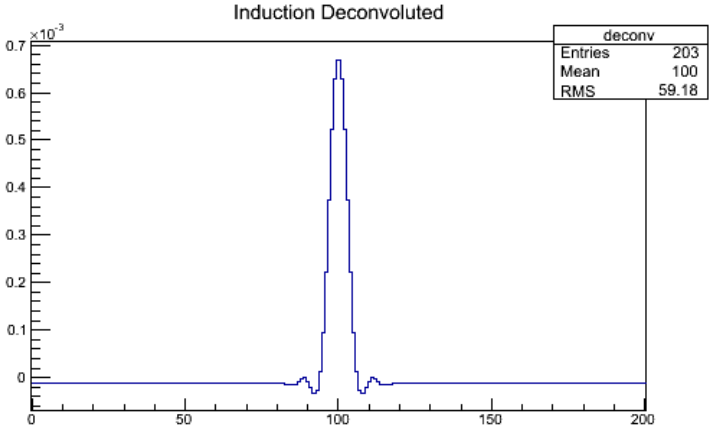
Collection





Induction





Filter Functions

- Filter function must be zero if the response function is zero.
  - Induction plane filter function must be zero at zero frequency.
  - Time domain representation of induction plane filter has zero area (narrow positive peak, and wide negative peak peak, both centered at t=0).
- Optimal filter function is called "Wiener filter."
  - $F(f) = |R(f)|^2 / (|R(f)|^2 + |N(f)|^2)$
    - $R(f)$ = Response function.
    - $N(f)$ = Noise spectrum.
  - Not implemented.

Some Implementation Details (Microboone)

- Response functions, filter functions, and kernels live in SignalShapingServiceMicroBooNE service.
  - Electronics response and field response are hard-coded c++ functions.
  - Filter functions are stored as fcl string parameters, which are used to instantiate root TF1 functions.
  - Response functions are shifted in time to produce approximately zero time offset between raw data and (reconstructed) charge.
  - Filter functions are normalized to produce same peak height between raw data (RawDigit) and reconstructed charge (Wire).
- Noise is implemented separately in SimWireMicroBooNE module.

Issues (Microboone)

- Noise is not modeled correctly.
- Filter function is not optimal.
  - If SignalShapingService owned the noise spectrum, it could calculate the optimal Wiener filter function.
- Field response:
  - Overly simplistic, needs to be revisited or recalculated.
  - Same field response used for both microboone induction planes (this is definitely wrong).
  - Induced charge on non-nearest wires is not modeled (perhaps an issue for first induction plane).